Work supported by the
National Aeronautics and Space Administration

Tomorrow's Astrophysics Enabled by Today's SBIR

Mirror Technology Days
Albuquerque, NM 16-18 June, 2008

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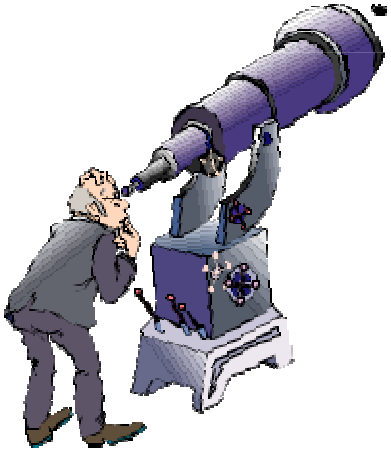
Optics SBIR for Astrophysics

2.01 -2.05



- Precision Spacecraft Formations for Telescope Systems
- Proximity Glare Suppression for Astronomical Coronagraphy
- Precision Deployable Optical Structures and Metrology
- Advanced Optical Component Systems
- Optics Manufacturing and Metrology for Telescope Optical Surfaces

SBIR for Astrophysics

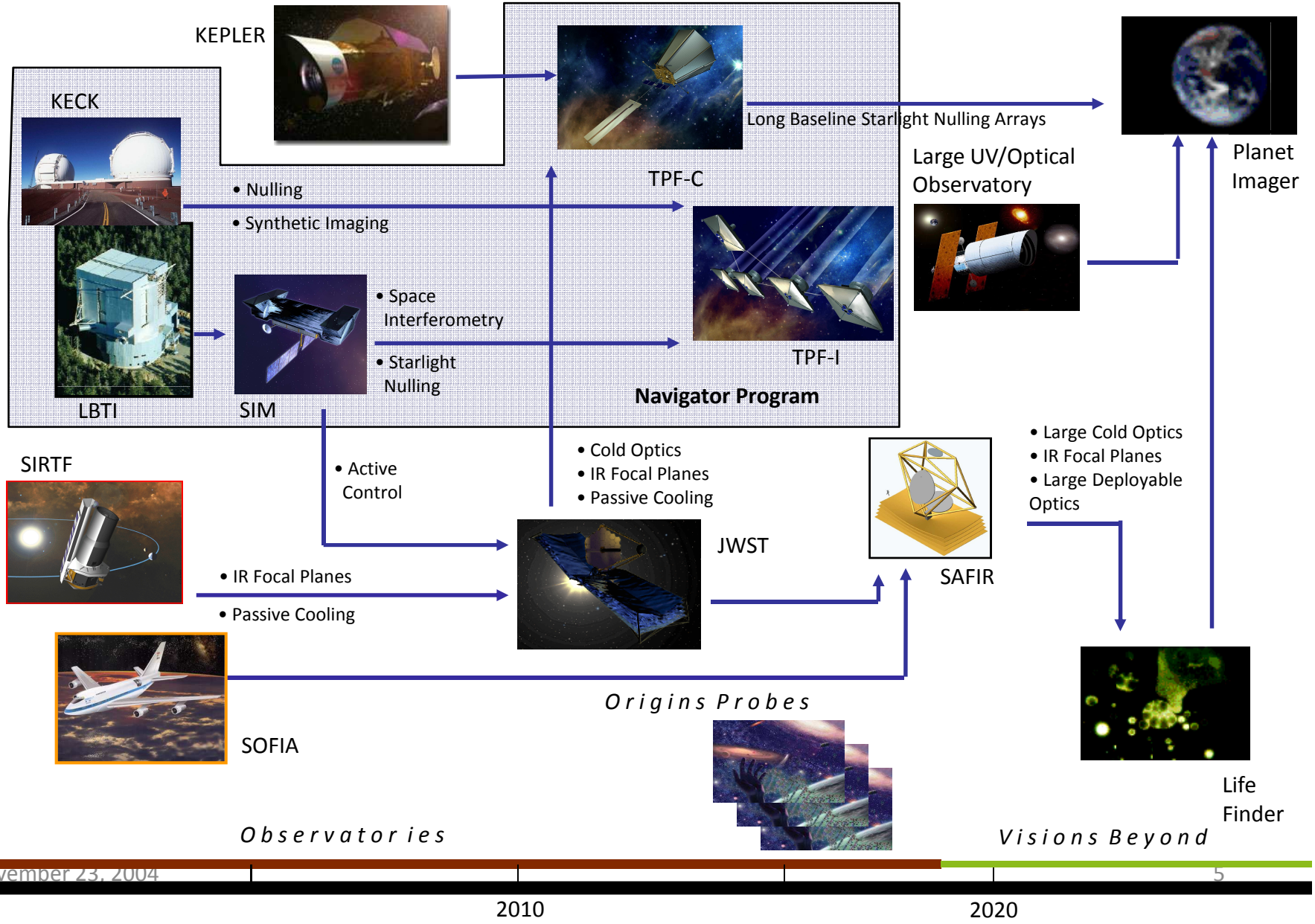
current events

- Astronomers convened the astronomy 2010 decade committee
- Advise & recommend:
  - Missions for new starts in 2010-2020
  - Science measurements & technology for 2010-2020 to 2030
- Requirements for technology to enables science measurements do not change much!
- Talk to the subtopic managers for more details

- http://sites.nationalacademies.org/bpa/index.htm


BEYOND EINSTEIN
ORIGINS
2010
2020

ExoPlanet Implementation Roadmap



ExoPlanet: Proximity Glare Suppression for Astronomical Coronagraphy

- Starlight supression demonstratioms
  - Reject scattered light so the image of an exo-planet can be separated from that of its parent
  - IR 10^6 Visible 10^9
- Wavefront sensing and control
  - To achieve the levels above systems need to be controlled to the sub nanometer level
  - Advances in: control algorithms, sensing, and deformable mirrors

ExoPlanet: Proximity Glare Suppression for Astronomical Coronagraphy

- Advanced Optics
  - Coronagraphic masks, spatial filters, coherent arrays of single-mode fiber optics
- Structures, Materials and Mechanisms
  - Low thermal expansion materials, micro dynamically stable mechanical interfaces
  - Vibration damping approaches

ExoPlanet: ExoPlanet: Proximity Glare Suppression for Astronomical Coronagraphy

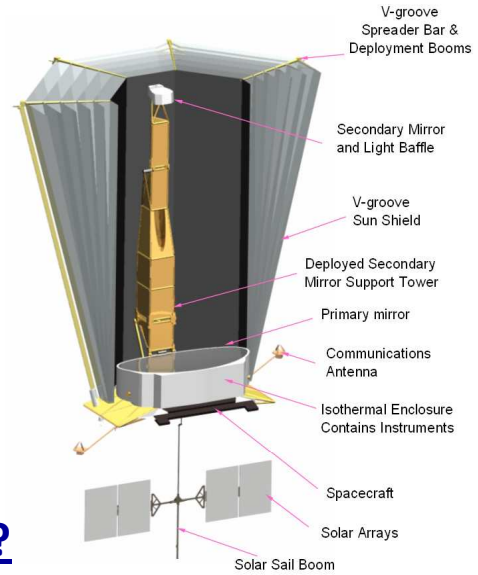
- System performance assessment
  - Systems now impossible to testNeed high density models that captures the physics properly
  - Seamlessly integrate thermal, mechanical and optical models to infer picometer performance on orbit based on nanometer level measurements on the ground.

Exo-planet search technology awards

recent

Boston Micromachines Corporation	Ultra-flat Tip-Tilt-Piston MEMS Deformable Mirror	High Contrast Astrophysical Imaging	
Iris AO, Inc.	Extreme-Precision MEMS Segmented Deformable Mirror	Optics and Optical Telescopes (including X-ray, UV, Visual, IR)	
Los Gatos Research	Nonintrusive Optical Thermometers for Real-Time Control of Fabrication Processes	Optics and Optical Telescopes (including X-ray, UV, Visual, IR)	
SySense, Inc.	Fault-Tolerant Precision Formation Guidance for Interferometry	Precision Formations for Interferometry	
TRS Ceramics, Inc.	Hybrid Electrostatic/Flextensional Deformable Membrane Mirror for Lightweight, Large Aperture and Cryogenic Space Telescopes	Large-Aperture Lightweight Cryogenic Telescope Components & Systems	
Xinetics, Inc.	Integrated Wave Front Corrector	High Contrast Astrophysical Imaging	

TPF Coronagraph System Objectives



What? TPF Coronagraph Observatory

- Large very fine primary mirror
- Wave front sensing and control with Deformable Mirror and camera
- Starlight suppression – baseline via focal and pupil plane masks and stops
- Control of diffraction and polarization effects
- Very stable structural and thermal control
- Very accurate modeling of wavefront propagation, component effects, structural and thermal performance
- Integral Field Spectrometer
- Additional Astrophysics instruments

Why?

- By performing wavefront correction, the scatter and diffraction from the classic coronagraph can be adequately controlled so that faint light from a planet next to a star can be detected
- The light from a detected planet and re-visits can validate that a planet is found and be evaluated for spectral bio-signatures
- Fine quality telescope and imaging will be used for other astronomy

How?

- Develop & improve state-of-the art technology (HCIT, DMs, coatings, mask & stops, modeling tools, on-orbit WFS&C, laser metrology)
- Model performance of components and verify through test bed experiments
- Fabricate large demonstration mirror to develop road map to meet TPF primary mirror reqts
- Analyze, develop and evaluate coronagraphic architectures and perform trades that lead to selection of optimum flight mission design

Current Technology Development

ITT Technology Demonstration Mirror: JPL-led contract to design, analysis, fabricate, test

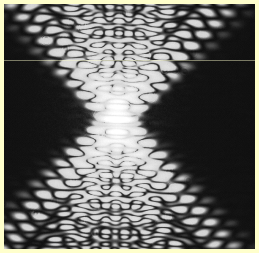
- lightweight fabrication process (based on ULE glass)
- coating application and test
- metrology

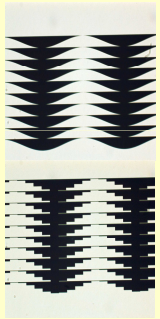
Deformable Mirrors

JPL & Xinetics, Inc.
left: 64x64 actuator model
right: 32x32 actuator model

Also purchasing 4 MEMS DMs for study/use by Princeton and GSFC

Mask Design and Analysis – TPF funded research at JPL, Berkeley, Ball Aerospace, and Princeton



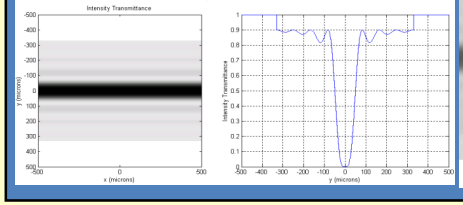


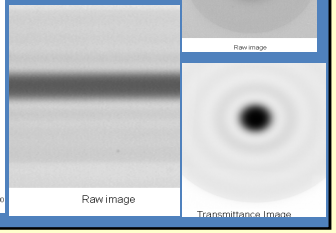
HEBS Glass Mask Design/Fabrication

3. Linear sinc^2:

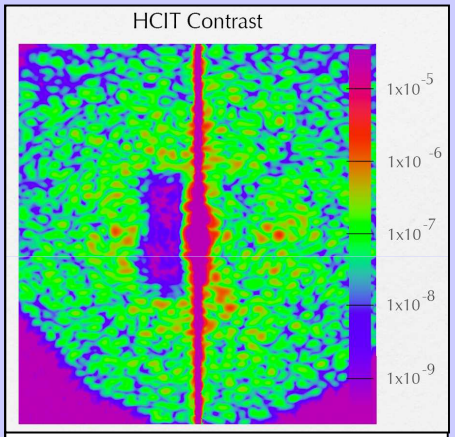
$$T(x) = T_{max}\left[1-\alpha\left[\frac{\sin(\pi x/w)}{\pi x/w}\right]^2\right]^{-2}$$

$T_{max} = 0.9,\ \alpha = 1$ (no OD limit), $w = 82.9\ \mu m,\ x_{max} = \pm 4 \times 82.9 = \pm 331.6\ \mu m$





High Contrast Imaging Testbed
Contrast Results to date: 1.5x10e-9



Data by Trauger, Burrows & Moody, HCIT May 2004

Mask Characterization Test Set - JPL

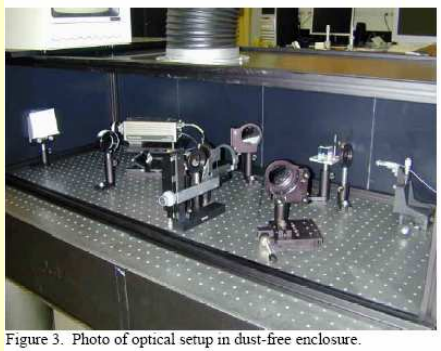
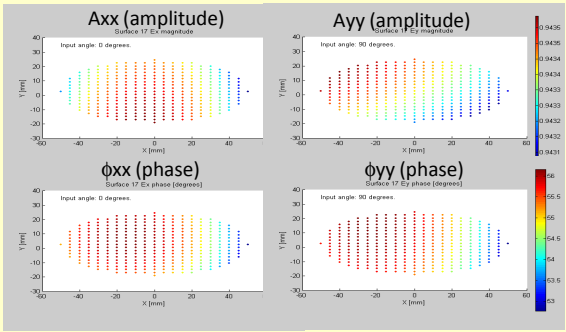


Figure 3. Photo of optical setup in dust-free enclosure.

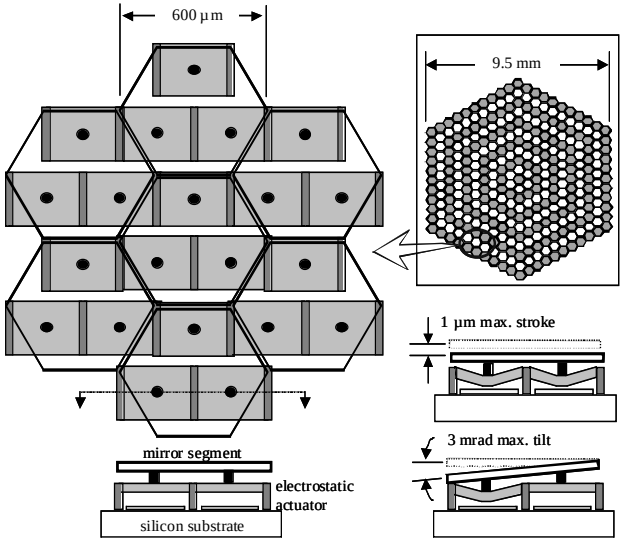
Coating performance analysis and measurement - JPL & GSFC

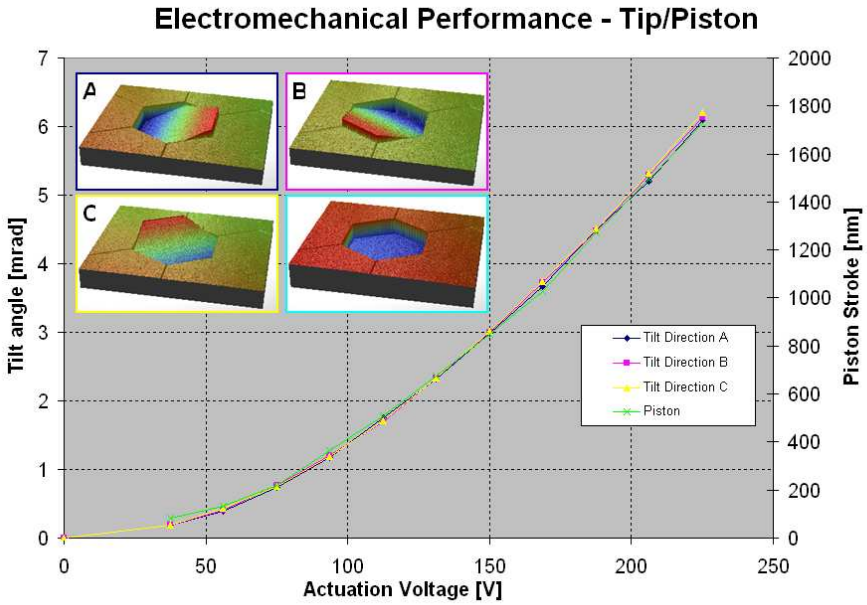


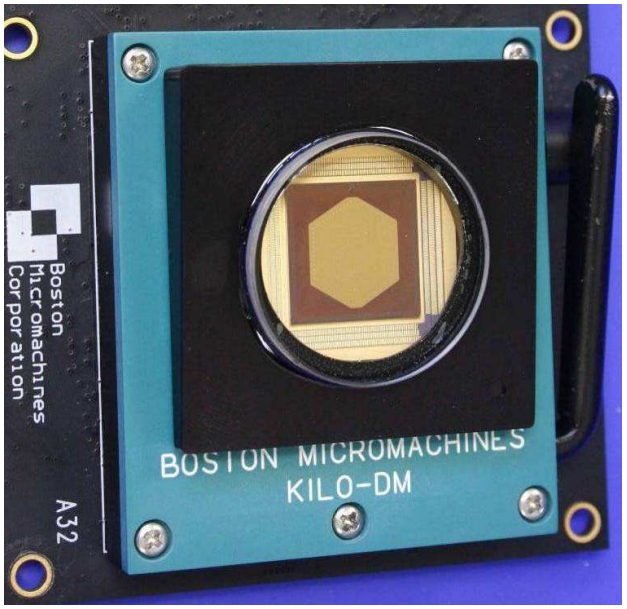
Risk reduction advanced concepts: Visible Nuller, Phase Induced Aperture Apodization

Boston Micromachines DM

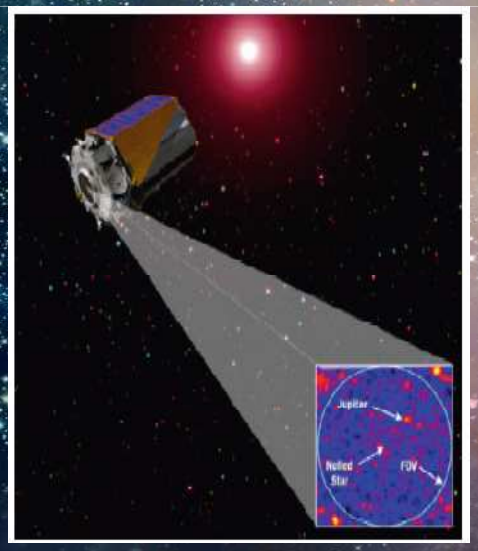
- Development history
  - TPF-C contract-69 segment proof of concept
  - SBIR phase 1 and 2-331 segment device
- Future development
  - 1027 segment device required

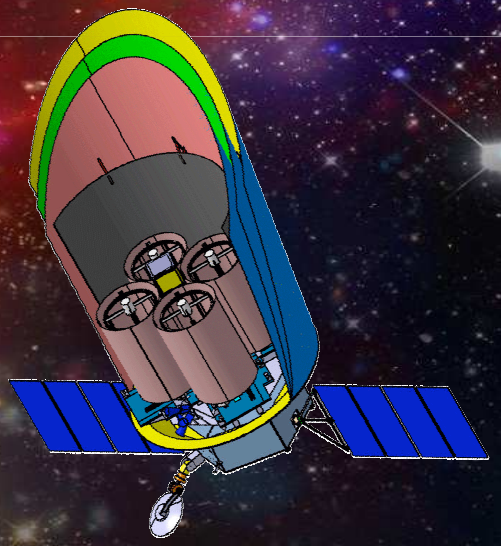






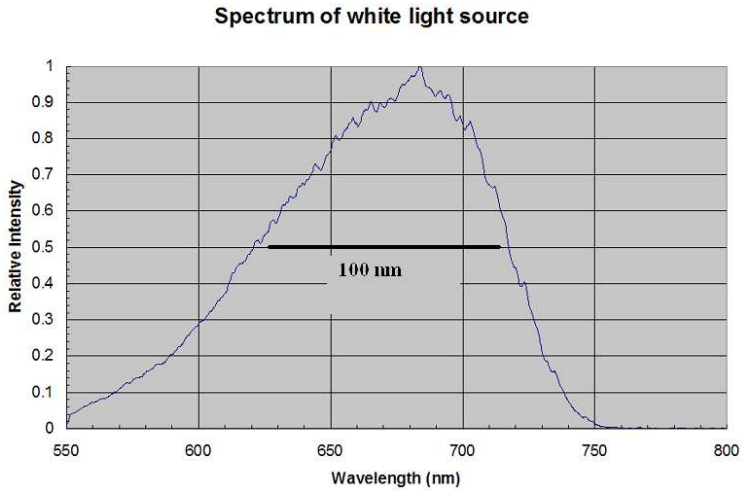
Technology Development in Support of Nulling Coronagraph Based Missions (EPIC and DAViNCI)

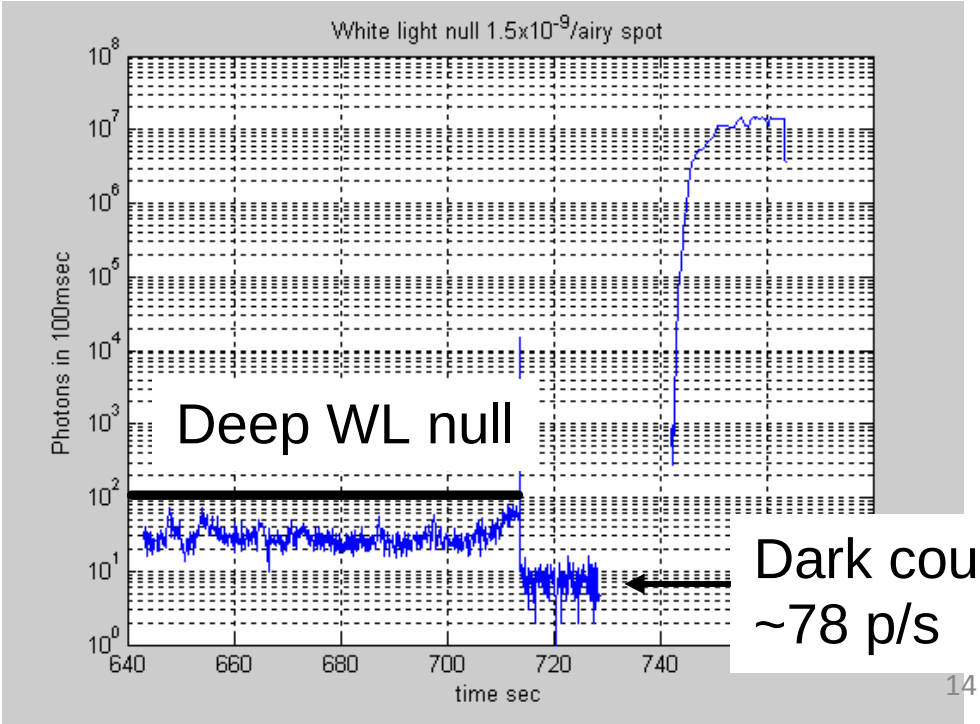




Nulling Status

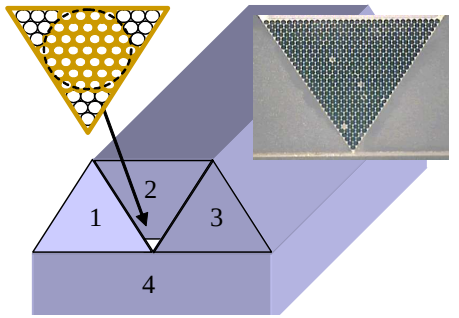
- (Upper) The 15% white light spectrum after propagation through one arm of the interferometer. The Full width at half maximum is 100 nm.
- (Lower) The resulting null plot showing 10^{-6} starlight suppression. (10^{-9}/airy spot, sufficient for EPIC)
- Results for laser light are 10 lower as required for DAViNCI
- Need demonstration of multi-pixel high contrast imaging





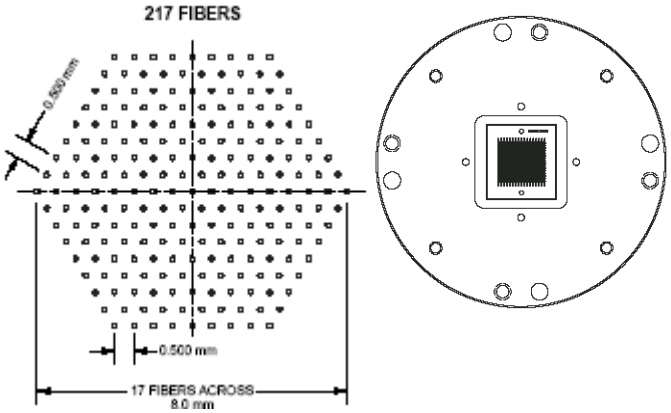
Single Mode Fiber Array assemblies

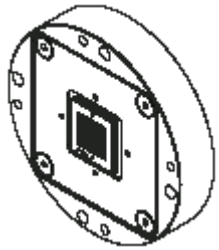
- Development History
  - TPFC & NASA funding (331 fibers without array)
  - U FL under TPF-C funding, 100 fibers with partial array integration
  - Fiberguide Industries
    - under current procurement contract
    - 217 fibers
    - To be fully integrated with custom lens array
- Future development
  - 1027 fibers fully integrated



10x10 fiber bundle (6.8 x 2.8 x 63.5 mm)

fiber ends illuminated by a microscope.





Technology Readiness Levels (TRL)

Technology evolves through stages before it is ready for a mission.

- **TRL 1** Basic principles observed and reported
- **TRL 2** Technology concept and/or application formulated
- **TRL 3** Analytical and experimental critical function and/or characteristic proof-of-concept
- **TRL 4** Component and/or breadboard validation in laboratory environment

Phase A Technology Efforts to Reduce Risk

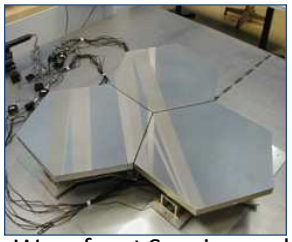
Mirror Actuators

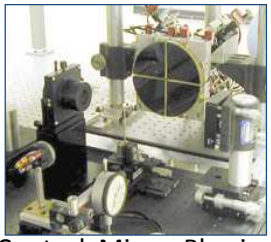
Beryllium Mirrors

AMSD

SBMD

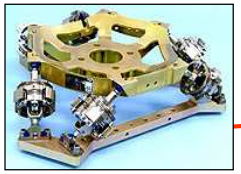
Mirror System



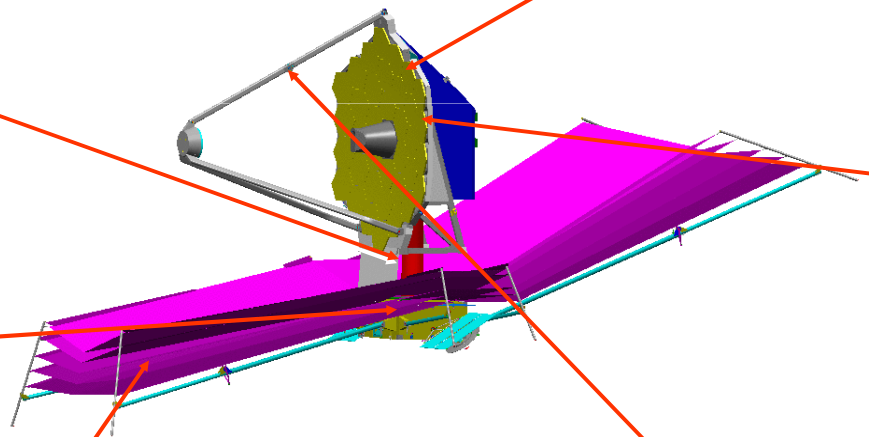


Wavefront Sensing and Control, Mirror Phasing

1 Hz OTE Isolators



Reaction Wheel Isolators



Cryogenic Deployable Optical Telescope Assembly (DOTA)

Half-Scale Sunshield Model

Secondary Mirror Structure Hinges

Primary Mirror Structure Hinges and Latches

SBIR for Astrophysics

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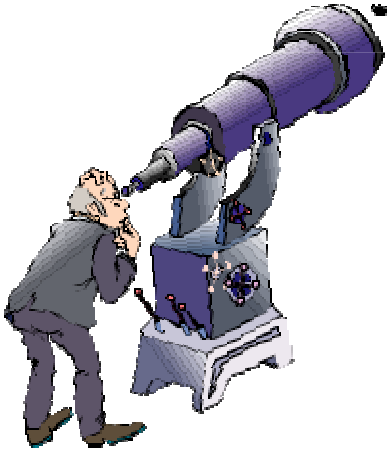

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Back Up Slides

SciMeasure SBIR

- The goal to build a small and versatile CCD controller and platform independent system for high speed low noise image readout
- Applications:
  - Wavefront sensing for adaptive optics
  - Interferometric wavefront sensing
  - Imaging of brain activity
- Funding:
  - Phase I SBIR to develop first generation system
  - Phase II SBIR to further reduce size and increase reliability

Detectors & electronics too!
Phase I Product

- Working product used in an AO system!
- Some concerns
  - Large, Heavy, runs HOT, relied on windows PC, large camera head

Phase II Product

Solved the Phase I problems

- Small form factor
- Reduced mass and power consumption
- Platform independent
- Modular/versatile design
- Increased dynamic range
- Field programmable logic

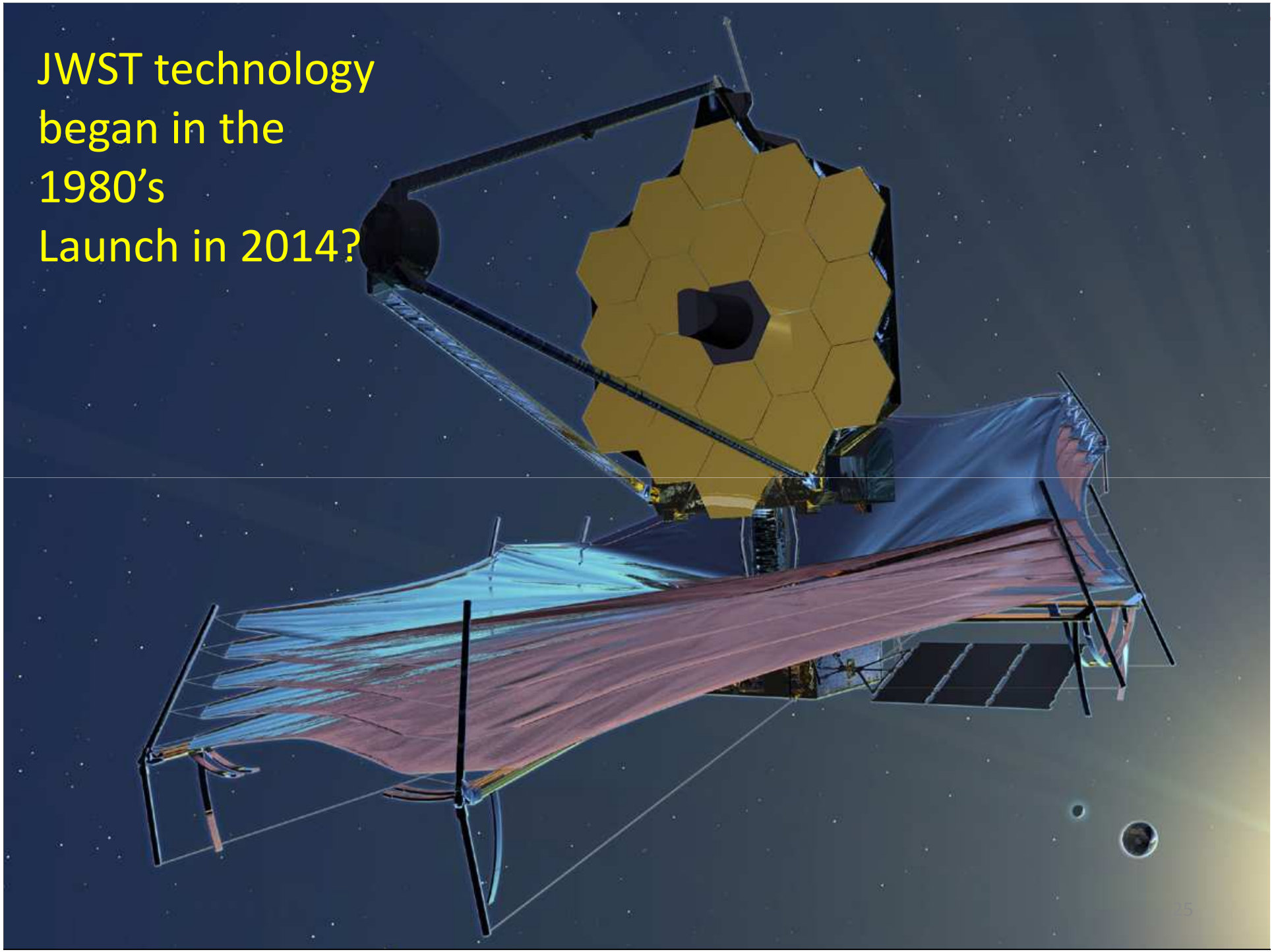
Excellent Read Noise

Noise (e-)	Pixel Rate (/sec/port)	Frame Rate (/sec)
3.0	80 kpix	40
4.0	250 kpix	125
6.9	1.5 Mpix	700
8.5	2.5 Mpix	1125

EEV CCD39 – 80x80 pixel frame size - Read Noise calculated from Photon Transfer curve
Maximum frame rates shown with no integration

Final Results

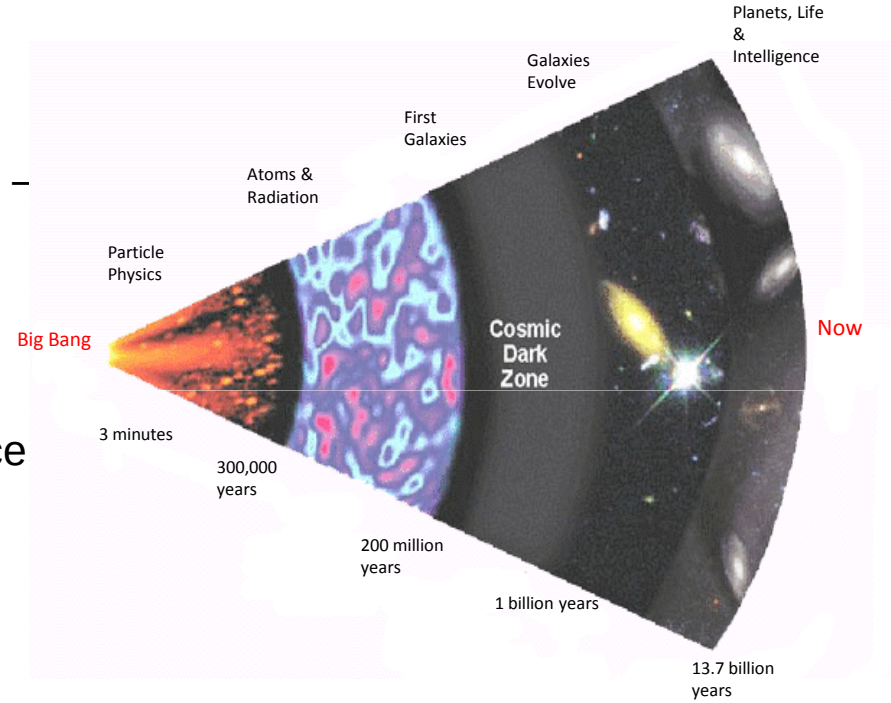
- SBIR has resulted in a commercial product
  - This is the definition of success
- Product is in use at the following places amount others
  - Palomar – Adaptive optics
  - JPL - Interferometer testbeds for flight
  - Keck – Guiding cameras
  - 6.5 meter MMT – Adaptive optics
- General lessons learned from SBIR
  - Make sure your phase I or II product has an application with your technical monitor
  - Frequent conversations with the technical monitor is good


JWST technology
began in the
1980's
Launch in 2014?

JWST Mission Introduction

- Mission Objective
  - Detailed study of the birth and evolution galaxies
    - See the “first light”
  - Study star and planet formation
  - Optimized for near infrared wavelength (0.6 – 28 microns)

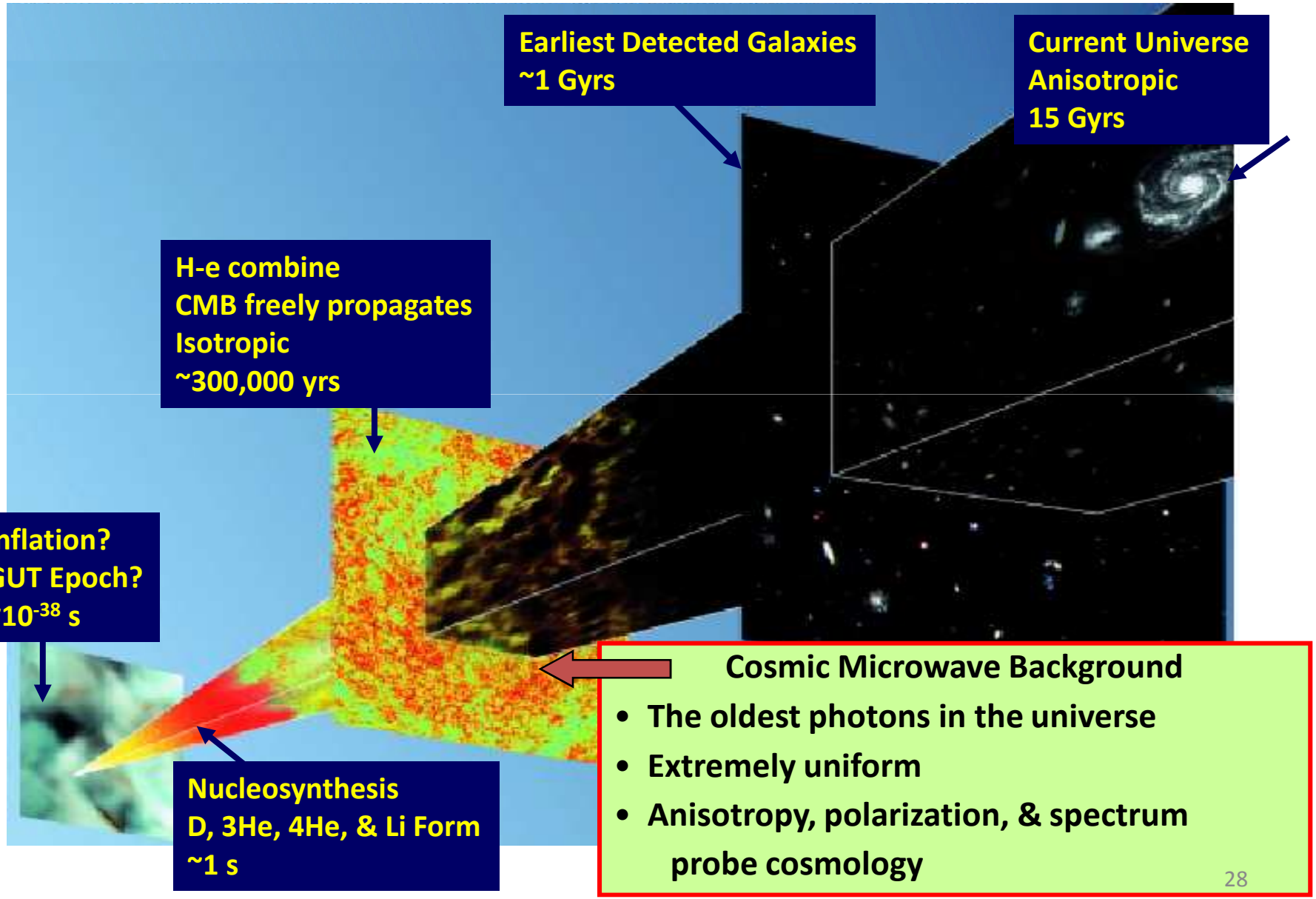
- Organization
  - International collaboration with ESA & CSA
  - Prime Contractor: Northrop Grumman Space Technology
  - Instruments:
    - Near Infrared Camera (NIR Cam) – Univ. of Arizona
    - Near Infrared Spectrometer (NIR Spec) – ESA
    - Mid-Infrared Instrument (MIRI) – JPL/ESA
    - Fine Guidance Sensor (FGS) – CSA



Technology Readiness Levels

- **Proof of Concept:**
- Analytical and experimental demonstration of hardware/software concepts that may or may not be incorporated into subsequent development and/or operational units.
-
- **Breadboard:**
- A low fidelity unit that demonstrates function only, without respect to form or fit in the case of hardware, or platform in the case of software. It often uses commercial and/or ad hoc components and is not intended to provide definitive information regarding operational performance.
-
- **Brassboard:**
- A medium fidelity functional unit that typically tries to make use of as much operational hardware/software as possible and begins to address scaling issues associated with the operational system. It does not have the engineering pedigree in all aspects, but is structured to be able to operate in simulated operational environments in order to assess performance of critical functions.
-
- **Proto-type Unit:**
- The proto-type unit demonstrates form, fit, and function at a scale deemed to be representative of the final product operating in its operational environment. A subscale test article provides fidelity sufficient to permit validation of analytical models capable of predicting the behavior of full-scale systems in an operational environment

EPIC: High-Sensitivity CMB Polarimeter



Cosmic Microwave Background

- The oldest photons in the universe
- Extremely uniform
- Anisotropy, polarization, & spectrum probe cosmology

SBIR Astrophysics

- **SBIR Optical Measuring Technique Applied to Projects:**
  Under the PY03 SBIR phase II project, Bauer Associates, Inc. of Wellesley, MA developed a working prototype instrument that utilizes a non-interferometric, optical technique for measuring absolute aspheric shape over the full surface of large mirrors to the nanometer level, without the need for known reference surfaces. => Recently, Bauer worked with the Smithsonian Astrophysical Observatory to use the prototype to measure the surface of NASA's High- Resolution X-Ray Explorer (HIREX) Pathfinder mirror. COTR: Timo Saha (GSFC, 03/23/08)

  Goddard Innovation Fund to Advance STTR Technology:
  The Phase III to Trex Enterprises Corporation and University of Alabama at Huntsville is an extension of the PY03 STTR Phase II project entitled "High Volume, Low-Cost Production Process for High-grade Silicon Carbide Optics." The specific objective is to demonstrate corrective grinding and figuring of a SiC mandrel. This would enable the demonstration of x-ray mirror fabrication from a SiC mandrel and comparison of x-ray mirrors from a SiC mandrel and from a fused quartz mandrel. =>The targeted application is Constellation-X project. The Constellation-X Observatory is a combination of several X-ray telescopes working in unison to generate the observing power of one giant telescope. COTR: Dave Content. (GSFC, 06/22/08)

  SBIR Mirror Concept Enables EPIC Mission Concept:
  Advances in MEMS and control electronics technology based on a PY05 SBIR Phase II project with Iris AO, Inc. enable the scaling up of extreme-precision MEMS deformable mirrors for EPIC (Extrasolar Planet Imaging Coronagraph) concept. => EPIC is a Discovery Mission concept designed to directly image and characterize extrasolar gas giant planets at typical distances of 2 to 20 AU from the parent star. COTR: Rick Lyon. (GSFC, 8/24/08)